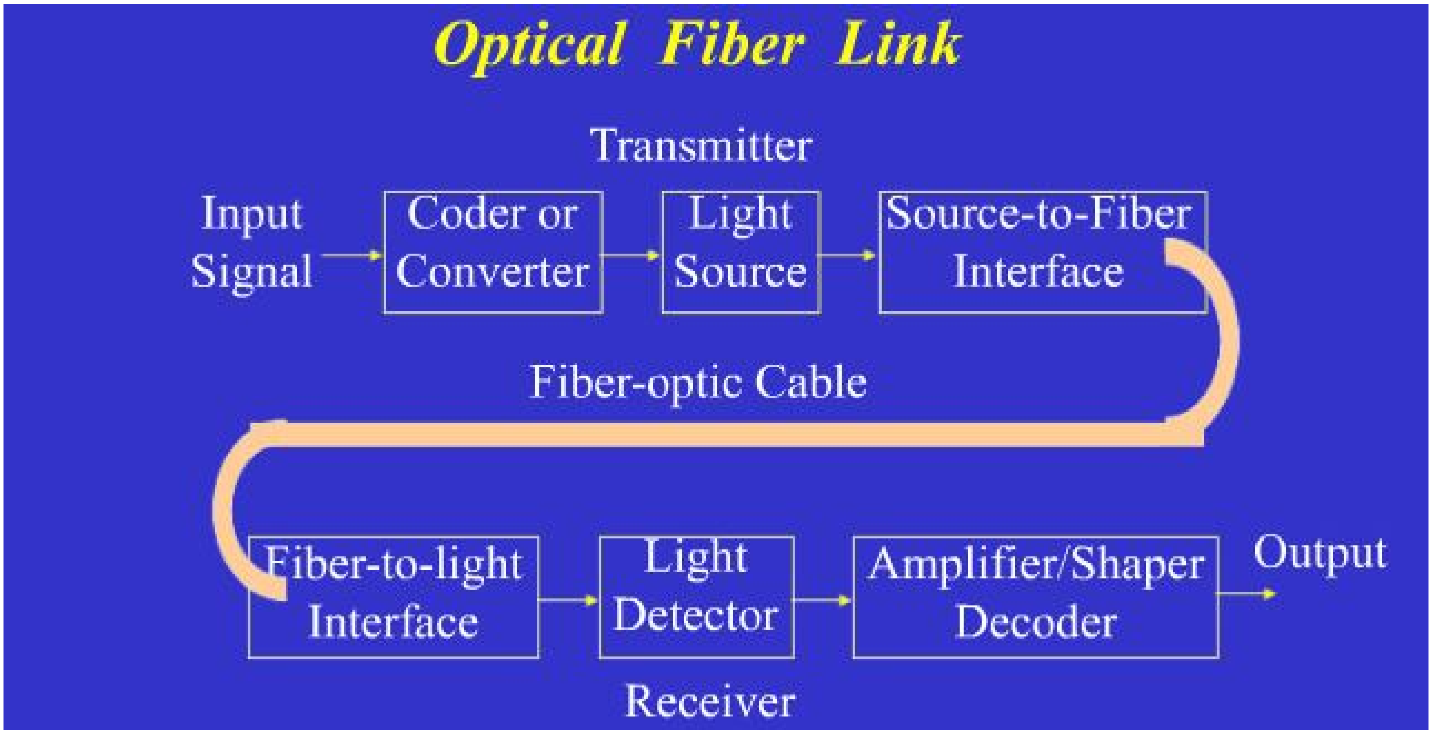
Semiconductor Sources for Optical Communications



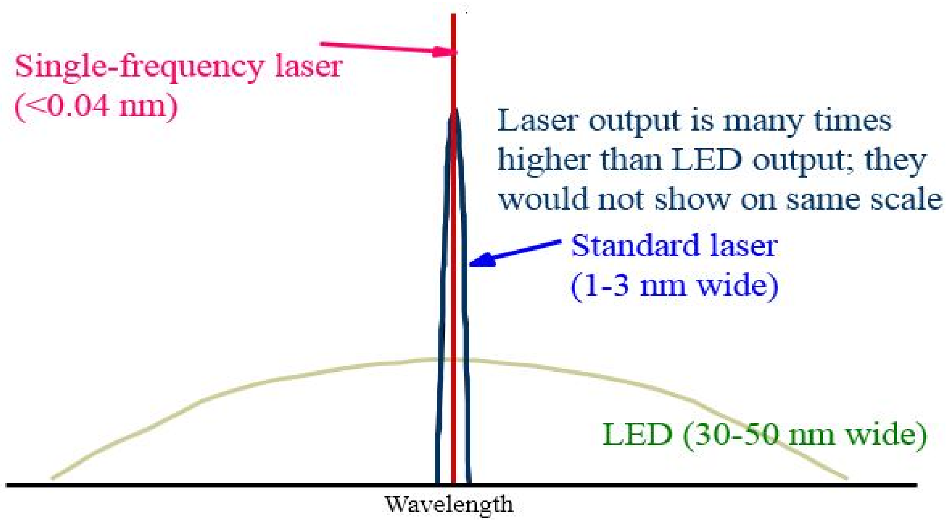
Considerations with Optical Sources

- Physical dimensions to suit the fiber
- Narrow radiation pattern (beam width)
- Linearity (output light power proportional to driving current)
- Ability to be directly modulated by varying driving current
- Fast response time (wide band)
- Adequate output power into the fiber
- Narrow spectral width (or line width)
- Stability and efficiency
- Driving circuit issues
- Reliability and cost

Semiconductor Light Sources

- A PN junction (that consists of direct band gap semiconductor materials) acts as the *active* or *recombination* region.
- When the PN junction is forward biased, electrons and holes recombine either *radiatively* (emitting photons) or *non-radiatively* (emitting heat). This is simple LED operation.
- In a LASER, the photon is further processed in a resonance cavity to achieve a *coherent, highly directional* optical beam with *narrow linewidth.*

LED vs. laser spectral width



Light Emission

- Basic LED operation: When an electron jumps from a higher energy state (E_c) to a lower energy state (E_v) the difference in energy $E_c - E_v$ is released either
  - as a photon of energy $E = h\nu$ (radiative recombination)
  - as heat (non-radiative recombination)
  - For fiber-optics, the LED should have a high radiance (light intensity), fast response time and a high quantum efficiency

OPERATING WAVELENGTH

Fiber optic communication systems operate in the

- 850-nm,
- 1300-nm, and
- 1550-nm wavelength windows.

Semiconductor sources are designed to operate at wavelengths that minimize optical fiber absorption and maximize system bandwidth

LED Wavelength

$$\lambda(\mu\text{m}) = \frac{1.2399}{E\ (\text{eV})}$$

λ = hc/E(eV)
λ = wavelength in microns
H = Planks constant
C = speed of light
E = Photon energy in eV

Bandgap Energy and Possible Wavelength Ranges in Various Materials

Material	Formula	Wavelength Range λ (μm)	Bandgap Energy W_g (eV)
Indium Phosphide	InP	0.92	1.35
Indium Arsenide	InAs	3.6	0.34
Gallium Phosphide	GaP	0.55	2.24
Gallium Arsenide	GaAs	0.87	1.42
Aluminium Arsenide	AlAs	0.59	2.09
Gallium Indium Phosphide	GaInP	0.64-0.68	1.82-1.94
Aluminium Gallium Arsenide	AlGaAs	0.8-0.9	1.4-1.55
Indium Gallium Arsenide	InGaAs	1.0-1.3	0.95-1.24
Indium Gallium Arsenide Phosphide	InGaAsP	0.9-1.7	0.73-1.35

- Semiconductor LEDs emit incoherent light.
- Spontaneous emission of light in semiconductor LEDs produces light waves that lack a fixed-phase relationship. Light waves that lack a fixed-phase relationship are referred to as incoherent light
- The use of LEDs in single mode systems is severely limited because they emit unfocused incoherent light.
- Even LEDs developed for single mode systems are unable to launch sufficient optical power into single mode fibers for many applications.
- LEDs are the preferred optical source for multimode systems because they can launch sufficient power at a lower cost than semiconductor LDs.
- Current flowing through a semiconductor optical source causes it to produce light.
- LEDs generally produce light through spontaneous emission when a current is passed through them.
- Spontaneous emission is the random generation of photons within the active layer of the LED. The emitted photons move in random directions. Only a certain percentage of the photons exit the semiconductor and are coupled into the fiber. Ma y of t he photons are absorbed by the LED materials and the energy dissipated as heat.
- Typically LEDs for the 850-nm region are fabricated using GaAs and AlGaAs. LEDs for the 1300-nm and 1550-nm regions are fabricated using InGaAsP and InP.

Semiconductor LDs

- **Semiconductor LDs emit coherent light.**
- **LDs produce light waves with a fixed-phase relationship (both spatial and temporal) between points on the electromagnetic wave.**
- **Light waves having a fixed-phase relationship are referred to as coherent light.**
- **Semiconductor LDs emit more focused light than LEDs, they are able to launch optical power into both single mode and multimode optical fibers.**
- **LDs are usually used only in single mode fiber systems because they require more complex driver circuitry and cost more than LEDs.**

Produced Optical Power

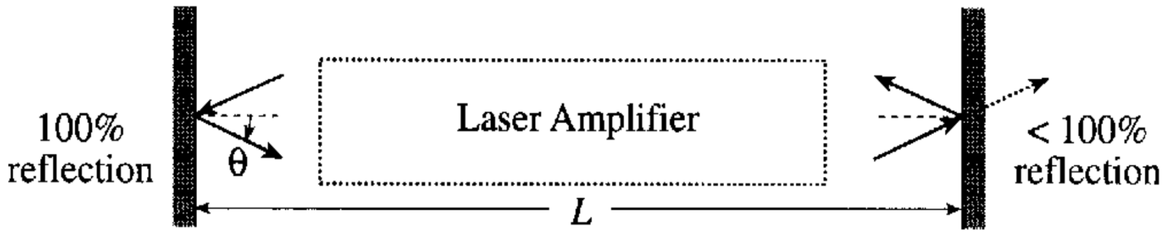
- Optical power produced by optical sources can range from microwatts (mW) for LEDs to tens of milliwatts (mW) for semiconductor LDs.
- However, it is not possible to effectively couple all the available optical power into the optical fiber for transmission.
- The amount of optical power coupled into the fiber is the relevant optical power. It depends on the following factors:
    - The angles over which the light is emitted
    - The size of the source's light-emitting area relative to the fiber core size
    - The alignment of the source and fiber
    - The coupling characteristics of the fiber (such as the NA and the refractive index profile)

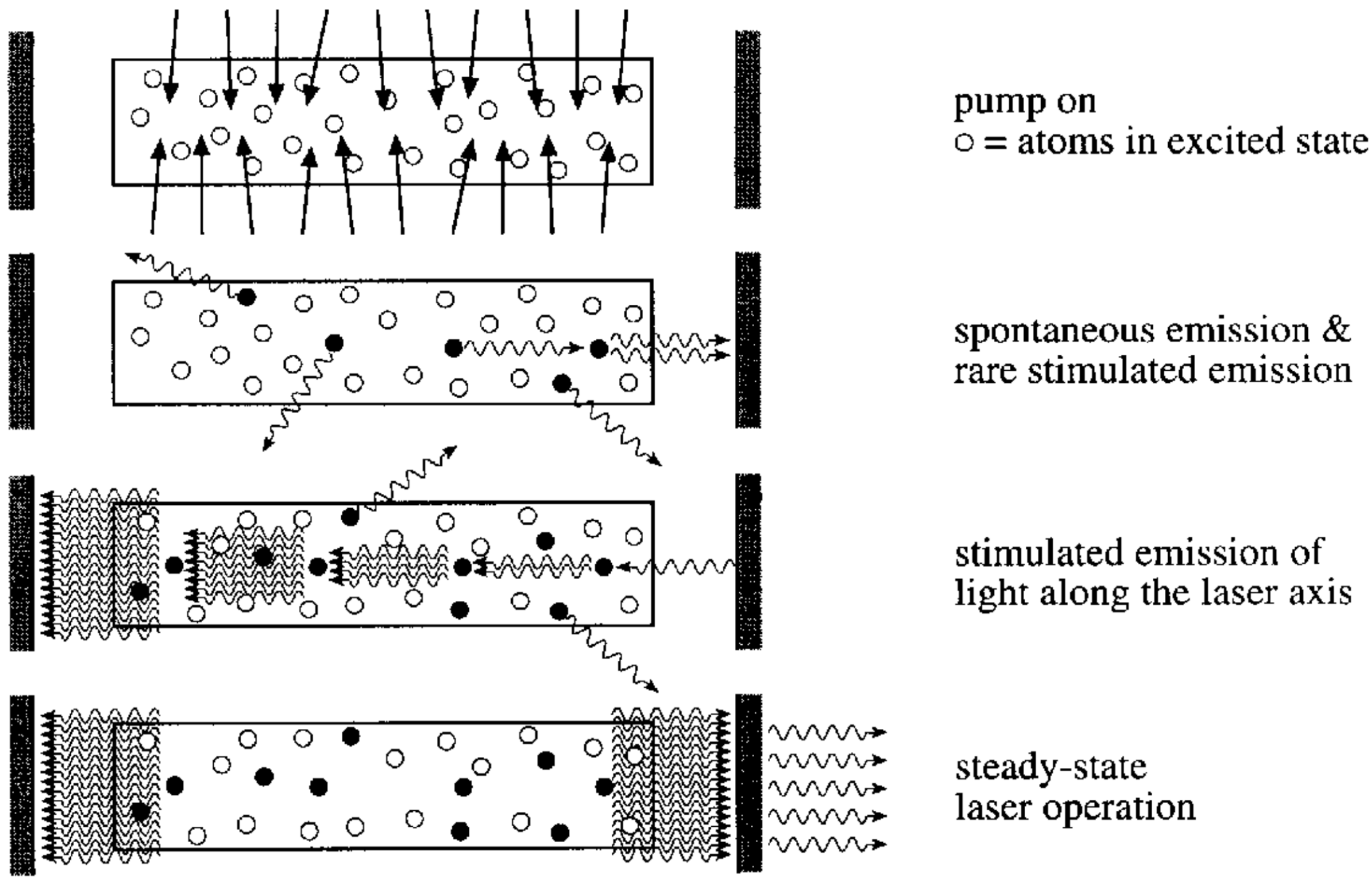
The LASER

- Light Amplification by 'Stimulated Emission' and Radiation (L A S E R)
- Coherent light (stimulated emission)
- Narrow beam width (very focused beam)
- High output power (amplification)
- Narrow line width because only few wavelength will experience a positive feedback and get amplified (optical filtering)

Fundamental Lasing Operation

- **Absorption:** An atom in the ground state might absorb a photon emitted by another atom, thus making a transition to an excited state.
- **Spontaneous Emission:** Random emission of a photon, which enables the atom to relax to the ground state.
- **Stimulated Emission:** An atom in an excited state might be stimulated to emit a photon by another incident photon.
- In Stimulated Emission incident and stimulated photons will have:
  - ✓ Identical energy → Identical wavelength → Narrow linewidth
  - ✓ Identical direction → Narrow beam width
  - ✓ Identical phase → Coherence and
  - ✓ Identical polarization





Modulation of Optical Sources

- Optical sources can be modulated either directly or externally.
- Direct modulation is done by modulating the driving current according to the message signal (digital or analog)
- is done after the light is *generated;* the laser is driven by a dc current and the modulation is done after that separately